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Dark Adaptation with Special Reference to Miners' Nystagmus

By W. J. WELLWOOD FERGUSON, M.B., Ch.B. *(Member)*

Summary

After discussing in general the process of dark adaptation, tests made in both control subjects and nystagmic miners are described. It is suggested that the primary cause of nystagmus among miners is poor illumination at the coal-face.

It may seem somewhat of a paradox to present a paper on dark adaptation to a Society whose interest is in illumination. It is a subject, however, of which a brief survey should not be without interest, especially when it is realised that it is the state of adaptation of the eye at any given moment that determines its sensitivity to glare.

(1) Day and Night Retinal Receptors

The retinal light perceptive elements of the eye are anatomically of two types, the rods and the cones, so called from their respective shapes. Their distribution in the retina is very different. The rods (estimated to be between 110 and 125 million in number) are absent in the central, or foveal, area. They are most closely packed in a ring some 5-6 mm. from the foveal centre, their density at the centre of this ring being approximately 160,000 per sq. mm., falling to about a quarter of this value towards the periphery. The cones, of which there are approximately 6½ million, are, on the other hand, most closely packed in and around the fovea, where there are some 120,000 per sq. mm.; the density diminishes rapidly from this point outwards.

Functionally, the rods are associated with vision at low illumination, while the cones function when the illumination values are much higher. The eyes of some nocturnal animals contain a relatively high percentage of rods, while in those of diurnal habits the reverse is true; indeed, some have all rod, and others all cone retinae. This is a broad statement, for there is still considerable debate about some of these matters, which, however, do not affect the subject under present consideration.

The retina as a whole is able to adapt itself for maximum efficiency under the prevailing conditions of illumination. Adaptation to good light is accompanied by a marked decrease in retinal sensitivity and is accomplished with great rapidity. On the other hand, adaptation to relative darkness involves a tremendous increase in retinal sensitivity and is a comparatively slow process, complete dark adaptation taking from 30-40 minutes.

(2) The Measurement of Dark Adaptation

The capacity for dark adaptation is measured by finding the illumination or threshold brightness which renders a given surface visible. After exposure to bright light the threshold brightness is high, but in darkness it gradually decreases. The method adopted for estimating dark adaptation in the investigations detailed later, is briefly as follows. After exposure to normal light, or preferably a bleaching light of known brightness, the subject is suddenly placed in complete darkness. His eyes fix a small red light placed to present the test surface at a visual angle of 7 degrees. At intervals the test surface, whose brightness can be varied, is exposed by means of a shutter for a known time. As retinal sensitivity increases, so the subject can distinguish flashes of diminishing intensity, until the final rod threshold is reached.

The usual form of adaptometer consists essentially of an illuminated test disc,

The author is lecturer in ophthalmology at the University of Sheffield. The manuscript of this paper was first received on October 26, 1951, and in revised form on December 12, 1951. The paper was presented at a sessional meeting of the Society held in London on December 11, 1951.

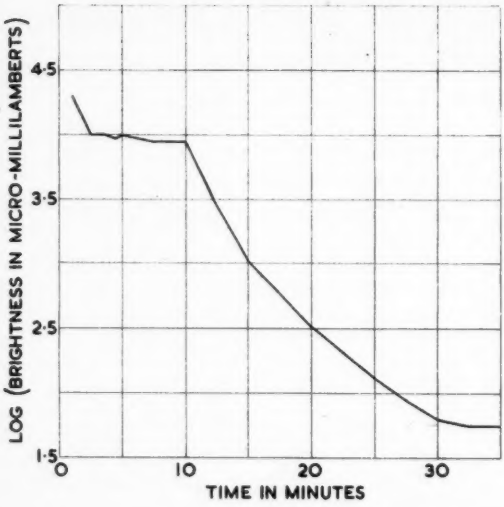

Fig. 1. Normal dark adaptation curve.

whose brightness can be varied by means of a neutral filter wedge. The disc itself is of opal glass, and in the Sheffield Adaptometer is covered by a diaphragm with a central aperture of 0.5 inches. Illumination of the disc is by a small lamp. The exposure of the disc to light from this lamp is controlled by a camera shutter. Behind the lamp is a photo-cell connected to a micro-ammeter, allowing for self-calibration. The filter wedge, operated by a rack and pinion, is placed between the light source and the opal screen. The whole is enclosed in a black, rectangular box from which projects a black, rectangular funnel with an aperture at the distant end sufficiently

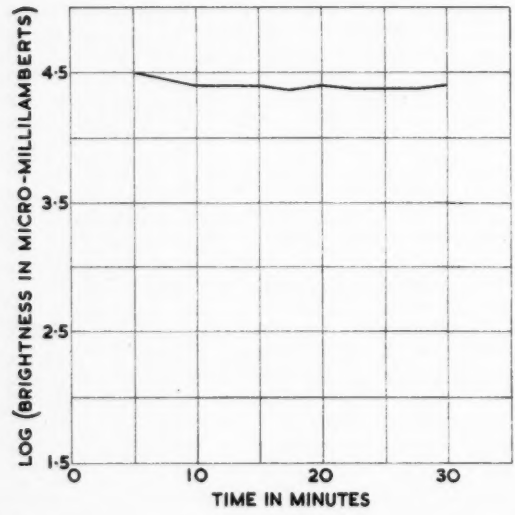

Fig. 2. Dark adaptation curve showing absence of rod response.
(A.B. Retinitis pigmentosa. 24.9.51.)

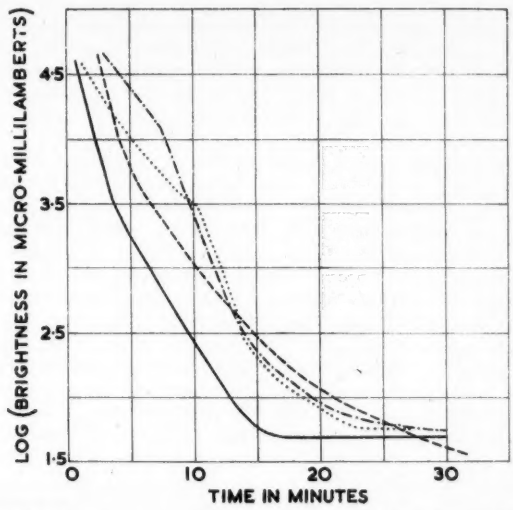

Fig. 3. Four cases of total congenital colour blindness. Cone-free type of dark adaptation curve.

large for the subject under investigation to see a small red fixation light above the opal screen.

The progress of dark adaptation is usually expressed graphically by a curve, the threshold brightness being plotted against the time spent in the dark. Fig. 1 shows an average curve for a normal subject; for convenience the brightness is plotted logarithmically. During the first few minutes the curve flattens horizontally; it then falls steeply, again gradually flattening after some 20 to 30 minutes. The first part represents the somewhat limited power of adaptation of the cones. The duration of the plateau is termed the cone-rod transition time, while the rest of the curve represents the adaptation of the rods. The time taken to achieve maximum rod adaptation is called the adaptation time, and the final brightness is termed the final rod threshold.

Fig. 2 shows the dark adaptation curve of a subject suffering from advanced retinitis pigmentosa. In this condition there is progressive atrophy of the retinal elements, commencing at the periphery and gradually extending inwards. In a late stage they can be considered as virtually rod free, as only the central area, consisting almost entirely of cones, survives. It will be seen that the curve continues the cone plateau indefinitely, the second part of the curve being absent. Night blindness is an outstanding symptom of this condition.

Fig. 3 shows, by contrast, the graphs of four subjects with the rare condition of total congenital colour blindness. These subjects behave in all respects as though the cones do not function, and it will be seen that the curves are of the rod type. One of the leading symptoms of total congenital colour blindness is great sensitivity to bright light (photophobia).

(3) Miners' Nystagmus

Miners' nystagmus is, in the main, a defect of the middle aged or elderly coal miner, usually commencing after 25-30 years' work underground. The outstanding visual symptoms are (i) difficulty in seeing in twilight or in the dark; (ii) an excessive sensitivity to glare; (iii) the spinning or oscillation of lights, or of objects looked at, and (iv) defective visual acuity, which is linked with the occurrence of the oscillations.

More general symptoms are headache, dizziness, particularly after stooping or

bending, and later in some subjects psychoneurotic symptoms, which are in the main those common to all forms of traumatic neurosis. The outstanding physical sign of the condition is oscillation of the eyeballs. The oscillations are of equal phase and typically occur in paroxysms of variable duration. In some subjects they may be present in daylight, even when the patient is sitting at rest; in others the oscillations may not appear in daylight until the patient has been subjected to exercise, and in others only when the illumination is diminished considerably, or in the dark. The amplitude of the oscillations varies considerably between individuals, as does the effect of the oscillations upon the individual. Some miners learn to tolerate it with little or no inconvenience, while others are greatly distressed thereby.

Mention has been made of the psychoneurotic symptoms which sometimes accompany or follow miners' nystagmus. It sometimes happens that after the disappearance of the oscillations these psychoneurotic symptoms continue, and may be so severe that disablement from work continues. It is this fact which accounts for the apparent oddity in the regulations concerning the certification of disablement from nystagmus, which allow certification even in the absence of oscillations of the eyeballs.

The term nystagmus is also applied to several other forms of abnormal ocular movement associated with certain conditions of the middle ear or of the central nervous system. There is also a form called congenital nystagmus, which is found in those in whom some disturbance of bilateral macular fixation has been present from birth or early infancy. The form of the oscillations in the former group do not resemble in any way those of miners' nystagmus. In the congenital variety, however, the oscillations are very similar, but are continuous instead of paroxysmal. The congenital nystagmic, although his eyes are constantly on the move, does not complain of the movement of objects, the presence of the condition since birth allowing him to interpret the series of images as a still one.

The similarity between congenital and miners' nystagmus suggests strongly that the latter is also due to some interference with macular fixation. The coal miner works underground in conditions which often make macular fixation impossible. Sharpley[1] in 1936, pointed out that a brightness of at least 0.01 foot-lamberts is necessary to maintain foveal function. Taking into consideration the poor reflection factor of coal, he points out that an illumination of 0.4 lumens per square foot is necessary to provide this brightness. It is not suggested that 0.4 lumens per square foot is the ideal illumination, but it is the minimum which permits foveal fixation.

It is not possible within the scope of this paper to consider in detail possible causes of miners' nystagmus. Causes that have been suggested are [2] [3] [4] [5] [6] :—

(i) Insufficient illumination;
(ii) The effect of poisonous gases;
(iii) Variations in temperature and humidity, this being related largely to the depth of the pit;
(iv) Fatigue of the oculomotor apparatus caused by working in confined spaces, necessitating a fixed and awkward posture while at work.

It has also been suggested that nystagmus may be of labyrinthine origin.

The present-day consensus of opinion favours defective illumination as the prime cause.

(4) The Dark Adaptation of Coal Miners

The frequent complaint of some degree of night blindness among sufferers from nystagmus prompted an investigation into the dark adaptation capacity of coal miners, both with and without nystagmus.

In 1920 Percival[7] pointed out that the light minimum was very greatly increased in all nystagmics whom he had examined, while Verbage[8] in 1940 found some disturbance of dark adaptation in over 70 per cent. of 91 miners incapacitated by nystagmus in the Dutch coalfield.

In order to measure the degree of night blindness present, two series of tests with

Table 1

Individual Variation of Final Rod Threshold on Repeated Tests (Sharpley)

Test number	Log (Threshold brightness in micro-millilamberts)
1	2.27
2	2.29
3	2.21
4	2.25
5	2.31
6	2.17
7	2.27
8	2.29
Mean	2.26
Standard deviation	0.047

adequate controls were made, one by Forbes Sharpley[9] among some 200 subjects, and the other by the author on some 1,500 subjects. Two points must be emphasised before dealing with the experiments. First, there is in normal subjects a slight though progressive deterioration of dark adaptation with increasing age. Secondly, there is a considerable range of dark adaptation even in corresponding age groups. A large number of subjects must thus be included if the results are to be statistically significant.

(5) New Observations

In Sharpley's investigations a Hecht-Schlaer Model 3 dark adaptometer was used. This instrument presents the test light in flashes of one-fifth of a second, uses a red fixation point, and tests a retinal area 7 deg. above the fovea. Table 1 shows the results of eight tests made by Sharpley on one of the control subjects (a non-miner) and gives some idea of the individual variations to be expected in tests of this type. Table 2 shows the results for 125 non-miners divided into age groups, showing the average value of the final threshold in each age group. Table 3 gives the results obtained from 73 coal miners; as most of these are in the 40-50 age group, the results have been adapted to this basis. It will be seen that for normal subjects (non-miners) the logarithm of the threshold brightness measured in micro-millilamberts for the age group 40-50 was 2.07. The values for miners (both with and without nystagmus) is significantly higher. The number of subjects examined in this series is not large enough to establish whether the threshold of nystagmics is significantly

Table 2

Final Rod Thresholds for Non-miners when completely Dark Adapted (Sharpley)

Age group (years)	10/20	20/30	30/40	40/50	50/60	60/70
Number of subjects	27	25	31	26	12	4
Log (Mean threshold brightness in micro-millilamberts)	1.75	1.86	1.94	2.07	2.15	2.23
Standard deviation	—	0.23	0.20	0.32	0.27	0.32

higher than that of normal coal-face workers, although the figures for groups 2 and 3 would tend to suggest that there is a significant difference.

In the second series of tests, some 1,500 subjects were examined, partly in the South Wales coalfield, and partly in the Sheffield district. The adaptometer used was a modification of the Wald adaptometer used in the Sheffield nutritional experiments made for the Medical Research Council during the war. This instrument, which also uses a red fixation point and presents the test surface at a 7-deg. visual angle, only exposes the test light in flashes of one-fiftieth of a second.

In the South Wales group were a large number of underground colliery workers, nearly all of whom worked at the coal face, and by contrast, a number of other

Table 3

Final Rod Thresholds for Coal Miners (Sharpley)

Group	Number in group	Average age	Log (Mean threshold brightness in micro-milli-lamberts)*	Standard Deviation
Certified cases with active nystagmus	15	47.2	2.30	0.25
Certified cases, recovering	21	49.0	2.56	0.52
Working, but with nystagmus	4	48.5	2.56	0.24
Suspected early cases	6	43.8	2.32	0.59
Controls: without any signs of nystagmus	27	44.8	2.34	0.44

* After correction for 40/50 age group.

Table 4

Final Rod Thresholds when Completely Dark Adapted (First Group—Ferguson)

	Log (Mean threshold brightness in micro-millilamberts)			
Age group (years)	20/30	30/40	40/50	50/60
Controls (250 subjects)	1.68	1.85	1.92	2.07
Underground colliery workers (1,425 subjects)	1.85	2.02	2.08	2.12
Miners with nystagmus (72 subjects)	—	2.4	2.75	2.99

workers varying from surface colliery workers to university students. No person showing any ocular abnormality, or who had to wear glasses of any degree of strength, was included in these tests. The Sheffield group included 75 coal miners suffering from miners' nystagmus and 125 miners without nystagmus. In this group each person was subjected to repeated tests on some four or five occasions in order to establish whether the individual variation among the nystagmics was in any way different to the average normal variability. The average variation in this group was found to be the same as for the control group. Table 4 shows a summary of the results for both the South Wales and Sheffield groups.

The results in this series agree closely with those reported by Sharpley. The actual figures of the final rod threshold are not, strictly speaking, comparable, as there

Table 5

Final Rod Thresholds when Completely Dark Adapted (Second Group—Ferguson)*

	Log (Mean threshold brightness in micro-millilamberts)		
Age group (years)	30/40	40/50	50/60
Controls (50 subjects)	1.45	1.56	1.80
Miners with nystagmus (70 subjects)	1.80	2.25	2.40

* The adaptometer used in this series was a modified form of the earlier instrument, and was re-calibrated at the National Physical Laboratory. It will be noted that this instrument gives lower readings than the original one both for controls and others, but that the proportional differences are similar.

are slight variations between adaptometers of different types. The tendencies, however, are comparable and point to the same conclusion, that the final threshold values for miners both with and without nystagmus are significantly higher than those for the non-mining controls. The Sheffield results also suggest that the threshold for miners with nystagmus is significantly higher than that for non-nystagmic miners.

Nutritional deficiency, particularly of vitamin A, is one of the causes of raised rod threshold. In order to find out whether this was a possible cause, tests were made with a large number of the Sheffield subjects. It was found that there was no evidence of nutritional deficiency, that the vitamin A content of the blood was normal, and, further, that the administration of saturating doses of vitamin A produced no alteration in the threshold of miners, whether with or without nystagmus.

Similar results were obtained from an investigation made by Dr. Dorothy Campbell([10]) in the Midland coalfield.

Since the preparation of the paper presented to the Stockholm meeting of the C.I.E. by Sharpley and the present author, further tests with 70 nystagmic miners have

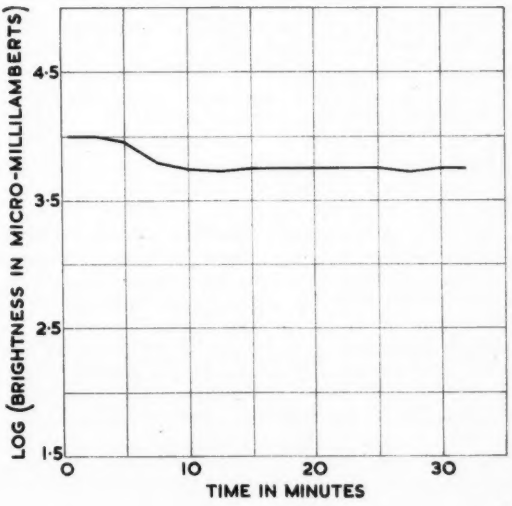

Fig. 4. Rod-free type of dark adaptation curve. (J. M. Miners' nystagmus. 6.10.51.)

been made in Sheffield. Table 5 shows a summary of the findings, which closely resemble those of the earlier series.

In a number of nystagmic subjects the dark adaptation curve tends to resemble very closely the rod-free type shown in Fig. 2. Fig. 4 gives one of the typical apparently rod-free curves from a severe case of nystagmus.

It has been suggested that the raised threshold may be due to psychological factors. Many miners with nystagmus develop some degree of neurosis. A recent paper by Dr. Dorothy Campbell[11] on this subject suggests that there is no significant difference in threshold between those without and those with psychological symptoms. In the tests made by the author, subjects with signs of neurosis were so few that no significant inference could be made, but it may be said that the adaptation curves of those with any degree of neurosis were not characterised by a higher threshold than the average nystagmic.

The common complaint among nystagmics of difficulty in the dark and corresponding sensitivity to glare, strongly suggests some change in the photochemical processes. Nystagmus itself is not as a rule found in the young miner, the vast majority of cases occurring after working underground for many years. During the winter months, many miners only see daylight during the week-end. It is possible that the phenomenon may be an expression of rod fatigue.

It has not so far been possible to make a histological examination of the retina of a miner suffering from nystagmus. In the absence of this, any suggestion of organic changes of the rod would be no more than guesswork. Certainly no organic changes are visible in the retina by means of the ophthalmoscope.

The chief interest, from the illuminating engineering point of view, is the presence of a number of objectively visible or measurable signs of ocular disorder in a condition ascribed to low levels of illumination.

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Discussion

DR. F. W. SHARPLEY: I think that when Dr. Ferguson and I first started work on dark adaptation of miners some years ago, we would have guessed that a miner who had been working in the dark for many years would see better in darkness than a man who had not. In fact we found the reverse to be true. We might have expected that the miner would have learned how to use his eyes in the dark even if his powers of dark adaptation were not better. During the last war airmen were trained to see better in the dark; I understand that some of these men were afterwards tested for dark adaptation but that it was no better than before training. They had, however, learned to interpret what they saw.

Dr. Ferguson suggests that some state of rod fatigue is involved with miners. That is an interesting suggestion and it would be worth following up. Under certain conditions rod vision becomes fatigued in a very short time. For example, if after

the eye is completely dark adapted you fixate on a spot of, say, red light, and slightly to the side of that spot there is a faint test spot of white light visible in the peripheral field of view, the test spot will completely disappear after a short time, owing presumably to some form of fatigue. It is admittedly very difficult to fixate with great precision for long, and the white light reappears immediately the eye moves even slightly. Whether all this is in any way related to Dr. Wellwood Ferguson's suggested explanation of miners' vision is, of course, doubtful.

With regard to dark adaptation in general, apart from miners, I think it is still not uncommonly believed that a person becomes adapted to the dark by his pupil opening and letting in more light. We know, however, that this is only a very small process of dark adaptation which is, in fact, due to the great increase of sensitivity in the retina itself.

Dr. Ferguson has mentioned two adaptometers, one which he uses and one which I used. An adaptometer may be designed to a large number of different specifications but different types will not generally give the same result for the same subject or groups of subjects. Moreover, the results are not necessarily directly related to each other. I think it is very desirable that some standard specification should be agreed. At present it is necessary to determine what is the value of dark adaptation for normal subjects as measured by the type of adaptometer in use, before one can detect abnormalities. Since, as Dr. Ferguson mentioned, the limits of normality are wide even for one age group, one must test a large number of subjects to determine the "normal" satisfactorily. Thus the use of a standard adaptometer would save much time as well as making inter-comparisons easier. I suggest that this is an interesting point which might possibly be taken up at a future meeting of the C.I.E.

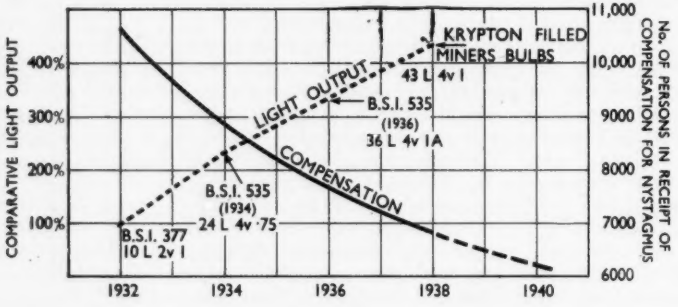
Another point which seems to me of some importance is that of dark adaptation from one level of illumination to another. The most usual method of determining adaptation is for the subject to remain in complete darkness for some 30 or 40 minutes after exposure to bright light before making the measurement. This is not the same thing as measuring adaptation to low brightness where the low level is not complete darkness. I think we are particularly interested in measuring from one level of illumination to another under certain conditions. For example, how long does a miner need for adaptation and at what rate should the illumination be decreased so that he can see the way in from the surface to the coal-face? As another example, there is the problem of seeing when entering a cinema, where you go fairly quickly from bright daylight into a low level of illumination inside, and it is difficult to find the way to a seat. It would be interesting to have measures of the time taken to adapt from one level to another in that way.

Again, Dr. Ferguson has mentioned the question of the possible Vitamin A deficiency in miners and shows that poor dark adaptation was not due to Vitamin A deficiency. As an illustration to show that the effect on night vision of Vitamin A deficiency is not something imaginary, I might mention the case of a man whom I tested at the Nuffield Laboratory of Ophthalmology. He came because he found that he could not see to cycle at night. Working as a storekeeper at an R.A.F. aerodrome, he cycled to his home across fields and dark paths but the time came when he could do this no more, as he was falling from his cycle. When I tested him I found that his dark adaptation was abnormally low. He was given some concentrated Vitamin A pills and I tested him again after about a week. The improvement was dramatic. He could see much better than before and after a month or two was practically normal. We found that he had been a farm labourer before taking up war work and was accustomed to eating plenty of butter and eggs, all rich in Vitamin A, and that he had a bad diet from the Vitamin A point of view in the R.A.F. as he did not like much of the food.

Dr. Ferguson did not have time to say anything about dark adaptation as regards colour and the change in sensitivity to the spectrum. That is of great interest and it

would be of value to know something about it. Such knowledge might help in the lighting of photographic film factories, where it is necessary to provide a light which will enable the workers to see clearly and yet will not fog the sensitive material.

MR. T. J. SACK: We have had demonstrated fairly conclusively to us that miners' nystagmus is due to low illumination. I have compiled a graph from Government statistics which shows how, during many years, the compensation for miners' nystagmus has progressively decreased as the illumination from the miner's lamp has been increased. The curves show the comparative light output from the miner's bulb, and the number of cases of miners' nystagmus in each of the corresponding years.



In 1932 the first specification for miners' bulbs BS.377 was produced, which covered 2-volt 1-amp. lamps having a lumen output of only 10. In 1934 BS.535 was produced, covering a 4-volt 0.75-amp. lamp which had a lumen output of 24; in 1936 BS.535 included a 4-volt 1-amp. lamp which had a lumen output of 36; in 1938 a 4-volt 1-amp. Krypton filled lamp was produced which had a lumen output of 43. To-day that output has been increased to 50 lumens. Thus during the period 1932 to 1950 miners' lighting has been improved five times. The number of miners receiving compensation for nystagmus has been reduced from 10,638 in 1932 to 7,000 in 1938.

According to the official report (issued by the Home Office in 1938) of the " Departmental Committee on certain questions arising under Workmen's Compensation Acts," " the cost of miners' nystagmus is at present about £450,000 a year "—a cost for compensation of about £60 per person. I feel that the lighting industry has done a good job in increasing the illumination the miner enjoys and accordingly decreasing the number of cases of miners' nystagmus.

In the United States miners' nystagmus is almost unknown. There they use cap lamps, which give very much more light than hand lamps, and it is significant that the National Coal Board has decided to standardise cap lamps in this country.

DR. W. S. STILES: There is a point which interested me particularly and that is that people who have congenital colour blindness have good night vision and suffer from exposure to light. The miner with nystagmus also suffers on coming into the light, and yet his night vision and dark adaptation are impaired. Therefore, we have a similar symptom—photophobia—connected on the one hand with good, on the other hand with impaired, night vision. I wonder whether Dr. Ferguson has any remarks on that particular point.

Could we hear something about the angular magnitude of the oscillations of nystagmus? If these are large, and if the test stimulus of an adaptometer is small, would the threshold measured on the adaptometer be affected by the drawing out of

the retinal image into an arc? This might be an effect additional to that arising from a change in the actual retinal sensitivity.

Finally, in photographic factories there are people working under very low illumination levels for very long periods. Has Dr. Ferguson any experience of such workers developing nystagmus?

MR. W. H. DODGSON: I was surprised by the psychiatrists' theory of the cause of nystagmus and feel that they can have had no experience of miners in their actual working conditions, because the miner judges the state of the roof and floor by his ear and can tell what is going to happen by the noises given out by the props—miners usually say that the props talk to them.

In regard to dark adaptation, it is now becoming common practice in new main roads to start at the cage door with about 6 lumens per square foot, tailing off within about 100 yards to 0.5 lumens per square foot, carrying on at that level until the face is almost reached, when the fittings are spaced out at greater intervals until main road lighting is extinguished—that is, when there is no special face lighting.

The use of fluorescent lamps would probably cut out nystagmus eventually, but the difficulty is in moving these heavy units each shift. The best possibility I think for lighting the coal-face in the future is a 6-volt fluorescent lamp operated by a vibrator invertor. This gives a 6-in. light source and will provide good general illumination which should improve the miners' conditions. This unit is being developed, but the principal objection to its use at present is the weight, as the miner objects to carrying a heavy hand lamp.

DR. R. G. HOPKINSON: There are two comments which I should like to make, both concerning possible clinical methods of checking the onset of this disease before the normal symptoms become appreciable. I wonder whether any work has been done on the shape of the dark adaptation curves and how they change with the progress of the disease. The changes which occur, and which are noted in an advanced state of nystagmus, appear to be changes in the shape of the curve as well as changes in the level of dark adaptation. Most of the figures which have appeared in the tables have been concerned with the final sensitivity. It might be of interest to know whether the change in the shape would be noted long before any serious symptoms have been found in the ordinary way.

There seem to be large variations in the rate of dark adaptation even in people who are normally called average. For example, I have found in testing a number of people who were by no means night blind, that quite a number of them adapted very quickly indeed, particularly in the initial portion of the curves; some people were quite different from others, but all were perfectly normal because their sensitivity was well down into the normal region.

The other point is that if the changes which occur are retinal, as Dr. Ferguson suggests, should not they show in some change of sensitivity to a flickering light source and also in the changed sensitivity to glare? We know that retinal rods are more sensitive to flicker changes than cones, and consequently if the retinal changes are in the rods one would imagine some change in the flicker sensitivity to be shown, possibly by the region of the periphery in which flicker is first noticed. Since sufferers from nystagmus complain of increased sensitivity to glare, one would imagine that one might be able to predict the onset of the condition before the advanced stages are reached by discovering the amount of increase in sensitivity in the early stages.

One further point. I asked one or two people in Stockholm about the iron workers and how they got on during the long Arctic night and whether they had any trouble with nystagmus or similar complaints, because there they have three or four months without daylight. The answer was that they did not have nystagmus. There

was, of course, plenty of electric light about, but even before they had electric light in the iron mines there was never any trouble.

MR. K. OLDHAM SMITH: It seems to me that one of the problems which has been brought to light by this paper is that of glare which is obviously inevitable in coal mines because of the low roof which is always in the field of view. It has always seemed to me that glare is a very real problem. Even light sources of low brightness are very trying, and I wonder whether glare is a contributory cause of miners' nystagmus? Furthermore, with the increased brightness of the light sources now coming into use, will this cause an increase of eye trouble, including both nystagmus and other eye defects?

MR. C. R. BICKNELL: Dr. Ferguson referred to congenital nystagmus, which I understand to mean that the defect is present from birth. Is it possible for a nystagmic to cause nystagmus in his progeny in the normal processes of reproduction, i.e., can it be inherited? I understand that the ordinary type of nystagmus contracted by miners is curable. Can congenital nystagmus be cured also?

Dr. Ferguson stated that dark adaptometers cannot reproduce results from time to time, but I take it that the percentage differences between results obtained at different times would be the same. If so, of course, that is all one needs for comparison purposes.

I have had some experience of the rectification of myopia by exercises and had it stated to me that colour blindness can be cured in this way. Is this really so?

MR. J. B. COLLINS: I was interested to hear Dr. Ferguson say that nystagmus was usually associated with some neurosis. There is some support at the present time for the theory that visual fatigue occurs in the central nervous system and I wonder whether it might be there one should look rather than in the retina for the fundamental causes of miners' nystagmus. It seems strange that nystagmic miners are photophobic as well as having poor powers of dark adaptation if the condition is merely due to reduced sensitivity of the retinal rods.

MR. J. G. CHRISTOPHER: I would like to ask Dr. Ferguson one or two questions. The threshold levels which he showed seem very low—are these related to conditions found in a mine? I mention this because he spoke of miners with nystagmus having to be led about, presumably because they had reached their threshold levels. Are the two conditions related? Do the conditions of the mines in fact approach the threshold values?

I should like to know, as far as the tests are concerned, why a red disc is used with the dark adaptometer because normally one reckons that the rods are not colour sensitive. I was interested in the reference to other industries—those who are engaged in photographic paper processing appear to be working in even darker conditions than miners and it would be interesting to know if any cases of nystagmus have occurred.

With a cap lamp presumably the level of illumination on the working plane is varying very considerably the whole time. Has that point been investigated and does it bear any relation to the question of nystagmus?

Another point regarding the question of glare. It was mentioned that the miner suffering from nystagmus on coming to the surface complains, for example, of glare from a cycle lamp; would not that be more a foveal condition than related to the rods with which nystagmus seems to be linked?

MR. D. A. GREEN: It has been mentioned that the minimum illumination required to create the necessary brightness suitable for working in coal mines is 0.4 lumens per

square foot. I feel that little importance can be attached to this figure, unless the ratio between the brightness created by the 0.4 lumens per square foot and the brightness of the actual light source is known. The importance of this ratio is that visibility is, among other things, affected by the glare caused by the brightness of the light source, i.e., visibility can be quite good at an illumination of 0.4 lumens per square foot if the light source is screened from the line of sight; on the other hand it can be very poor if the light source is directly in the line of sight.

I would ask Dr. Ferguson which of the following suggestions he would recommend the lighting engineer to follow: (a) Increase the value of illumination at the working plane, thereby increasing the brightness of the working surface, even if this means increasing glare from the light source (always providing that the ratio mentioned above is not increased), or (b) Maintain an illumination of 0.4 lumens per square foot but reduce the brightness of the source within the critical angles by stricter control of the light emitted.

DR. W. J. WELLWOOD FERGUSON (replying to the discussion): Dr. Sharpley referred to the question of airmen being trained to see better in the dark. The training in no way increased their light threshold, but improved their faculty for recognising objects in poor illumination.

I agree with his remarks about adaptometers. The results between any two adaptometers are comparable for percentage differences only. The trend of the curves is the same, but the individual figures, including those for normal cases, would be different with each adaptometer.

A number of questions have been asked with reference to the apparent anomaly that there should occur oscillations, due to the inability to use the macula in conditions of illumination below cone level, at the same time as the apparent decrease in the adapting power of the rods. The answer is, I think, that in the absence of illumination sufficient to stimulate the cones the macula is out of action and is represented by a blind spot in the field of vision. Normal fixation is thus impossible, and is replaced by a kind of reflex oscillatory fixation such as is seen in cases of congenital nystagmus. On the other hand, in illumination levels which stimulate, in the main, only the rods, the miner has to rely on the rods for long periods at a time over many years. I suggest that it is a type of rod fatigue which causes an increase in the light threshold.

Mr. Sack's figures were extremely interesting, but figures representing the number of certified cases of nystagmus bear little if any relation to the total incidence of the disease. Many factors influence the certification of nystagmus. A man may be able to work although he has the disease, until some factor—which may be illness, domestic or other worry, fear of unemployment, or accident—breaks down his tolerance, and he becomes disabled. He would not appear in the official nystagmus figures until he had been certified and disabled as a result of the disease. The numbers of cases receiving compensation are, therefore, misleading, and do not represent the number of men who actually have oscillations of the eyes.

It is interesting that in the United States miners' nystagmus is no longer present. Their methods of mining, vastly different coal-faces and the less exacting safety regulations, admit of much better lighting than that which obtains in our pits, or in those on the continent of Europe generally. The question has been asked regarding the tapering of illumination in the pits; this question has been considered for some time now and is being treated as urgent.

I agree with Dr. Hopkinson on the possibility of diagnosing the condition in the early stages; that is one of the future developments of these investigations, as is the examination of a number of cases using flicker fields of vision.

Mr. Christopher asks about the level of lighting in the pits. The conditions, of

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course, do not approach the threshold value for rods, but in the main is below foveal level.

Mr. Dodgson raised an interesting sidelight on the so-called fear complex, which suggests that the movements of the eyes in nystagmus are due to the miner constantly looking at the roof and floor for signs of danger. The contrary is, of course, true. The miner listens rather than looks for these signs; a complaint often made to me is that increased mechanisation makes it impossible for them to listen.

Mr. Bicknell raised the question of heredity. The lesion causing congenital nystagmus is sometimes hereditary, the nystagmus itself being the result of the causative lesion. There is no evidence that miners' nystagmus is hereditary, and while recovery from miners' nystagmus occurs, congenital nystagmus is incurable.

I have not heard of colour blindness being cured by exercises.

In reply to Mr. Green I would recommend an increased value of illumination at the working plane.

Work on this subject is still continuing, particularly in regard to colour adaptation, and to the rate of adaptation from one level of illumination to another.

Dow Prize Competition

In memory of John Stewart Dow and in virtue of a bequest by him, the Illuminating Engineering Society offers a prize which will be awarded to the winners of a competition intended to encourage collaboration between students of illuminating engineering or those branches of engineering concerned with illumination, and students in other fields in which applied lighting plays an important part. While entries from individuals are not excluded, the competition is primarily intended for students working in collaboration. The winning entry will receive a total cash award of £75 and a certificate will be presented to each member of the winning team. Certificates of commendation will be awarded to any other entries of outstanding merit.

Conditions for the 1952 competition are given below. The competition will be set and judged by a panel of assessors appointed by the Illuminating Engineering Society, in co-operation with the Royal Institute of British Architects and the Institution of Electrical Engineers.

Conditions for the 1952 Prize

1. The Subject for the 1952 competition is the layout, artificial lighting and decoration of a ground-floor showroom.
2. Relevant documents with instructions as to the form which entries should take will be available on April 1; forms of application may now be obtained from the Secretary of the Illuminating Engineering Society, 32, Victoria-street, London, S.W.1.
3. The competition is open to anyone who, not having completed his twenty-sixth year by the opening date (i.e., April 1), can show that he is taking or has taken a course of instruction, or has had equivalent training of a nature appropriate to the subject of the competition. All members of a team must comply with these conditions.
4. Candidates must have been born on or after April 1, 1926.
5. The last date for submission of entries is November 30, 1952.
6. Candidates may be required to give to the assessors a verbal explanation of their schemes.
7. In the event of there being no entry of sufficient merit, the award may be withheld.
8. The assessors' judgment of the entries will be final. In all other matters relating to the competition, the decision of the Council of the I.E.S. shall be final.

The Control of Light by a Lighthouse Lens

By W. M. HAMPTON, Ph.D., B.Sc., F.R.I.C., F.Inst.P., F.S.G.T., *(Fellow)*

Summary

The conditions to be fulfilled by a lighthouse lens are briefly described and a short historical survey is made. Elementary theoretical requirements are discussed, with particular reference to the aberrations inherent in the use of glass lenses. Particulars are given of the various approximations which are necessary to make manufacture practicable and the methods used for calculating the axial intensity are described. Recent work on the factors controlling the conspicuity of such lights is discussed, including the Blondel-Rey correction for duration of flash. Methods for computing the range of a beam under various conditions are given, and the range is related to the Standard Visibility Code of the meteorological services. The practical application of these various features to typical lighthouses is described.

(1) Introduction

The use of lights as aids for mariners is probably as old as any application of light to human problems; two out of the Seven Wonders of the Ancient World were, in fact, lighthouses. The earliest visual aids consisted of simple fires either on a headland or in some form of crude brazier. The use of optical apparatus to increase the conspicuity of lights was a much later development, one of the earliest attempts being the use of mirrors of approximately paraboloidal form in Liverpool in 1763(1).

(2) Lighthouse Lenses

(2.1) Intended Purpose of a Lighthouse Lens

Before considering developments in the form of lenses or mirrors used for lighthouses, it is necessary to give some indication of the purpose that such optical apparatus is intended to fulfil. Most physicists and illuminating engineers look on a lens or a mirror as a device for producing an image of a light source at some point remote from the source. This photographic or magic lantern use of lenses makes it necessary to consider the direction and location of rays remote from the optical axis. The purpose of a lighthouse, or any other light projection apparatus, is to concentrate as much light as possible in a predetermined direction, and the system may be thought of as producing an image at infinity. This can be done by a relatively simple lens and a small point emitting light uniformly in all directions; the light is modified by the lens so that it emerges from the system parallel to the axis of symmetry. The emergent light is not strictly parallel, since it would only be parallel in a properly designed lens for that portion of the light which lies exactly on the optical centre. All such projected beams in effect are divergent, the divergence being brought about by the finite dimensions of the light source itself. If such a lens, with a light source at the focus, be viewed along the optical axis from a considerable distance, the whole lens appears to be filled with light, or to be "fully flashed," as it is called in lighthouse terminology. Subject only to absorption and similar losses in the apparatus, the brightness of this lens area is the same as that of the light source, so that the effective intensity along the optical axis is equivalent to the brightness of the light source multiplied by the area projected in that direction. A relatively simple lens is sufficiently accurate for projection in directions along the optical axis, provided that the source size is small relative to the size of the lens. Most of the complications of modern lenses are due

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to the fact that a geometrical image has to be produced in directions at a considerable angle to the optical axis.

(2.2) Origin of Lenses for Lighthouses

The use of a simple lens as a burning-glass was known very early in history and it was obvious that a large lens capable of dealing with a large light source would inevitably be very thick and heavy (Fig. 1). In 1748 Buffon[2] suggested that the weight of the lens could be reduced very markedly by manufacturing it in echelon form. This type of lens was to be produced by grinding a solid block of glass in echelon form, each of the zones having the same radius of curvature, with the zones stepped back to maintain a reasonable maximum thickness. The manufacturing problems involved in producing a lens of this sort were so difficult of solution that it is doubtful if one was ever produced. In 1788 Condorcet[3] made the valuable suggestion that this lens should be produced from separate rings. There was however—then as there often is now—a big step between making a suggestion and converting it to a practical application, and the credit for this practical application must go to Augustin Fresnel[4]. In 1822 a programme suggested by Fresnel for the lighting of the French coasts was adopted by the French lighthouse authorities and it was when implementing this programme that Fresnel was led to consider the manufacture of lighthouse lenses. His early efforts resulted in lenses of polygonal plan instead of the original Condorcet idea of a circular plan. As Fresnel was not satisfied with this he invented a system of grinding these rings by combining a cross stroke with a rotational movement, thus translating his geometrical conception into a practical machine. This method is fundamentally the one that has been used ever since. He also introduced further improvements. The original suggestion for a stepped lens simply meant that a normal spherical curve was stepped back to reduce the weight of the lens, but when Fresnel studied the subject he realised that a better approximation could be achieved by altering the radius of curvature and centre of curvature for the various zones, in order to minimise the results of spherical aberration.

(2.3) Elementary Theory of Lenses

Consider what happens when light from a small source placed at the focus falls on an elementary ring of a lighthouse prism. In the first place, the light is deviated in such a way that after passing through the lens the main ray emerges in a horizontal direction. Secondly, the light, which diverges from a point at the centre of the light

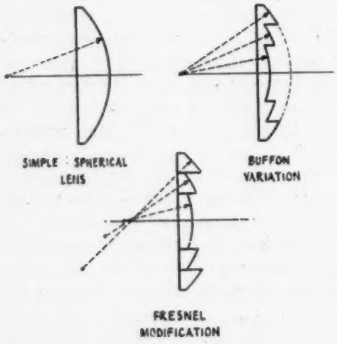


Fig. 1. Elementary lens forms.

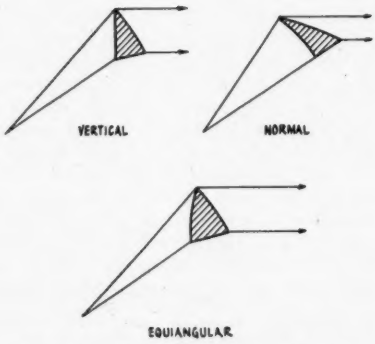


Fig. 2. Types of refracting prisms.

source, is made to emerge theoretically parallel by the use of a curve on one of the faces of the prism. This is the simple theory; but, in fact, the problem is more complex. There is no such thing as a point source, and so the beam emitted from a source of finite dimensions emerges as a cone, even though the lens is so designed that light diverging from a point source would be rendered parallel. The most that can be done here is to design for a theoretical point and accept the inevitable fact that the light from a practical source will be divergent. It can also be shown that the divergence due to the size of the source is not affected in the circumferential sense, but is increased in the radial sense, this increase being greater the further from the axis the prism is placed. Thus, with a spherical source at the focus, the circular cone which falls on the incident side of the prism emerges as an elliptical cone on the remote side of the prism, the major axis being in the radial direction. A further aberration is introduced by the fact that the angle of deviation is dependent on the refractive index of the glass, and since the glass has dispersion the refractive index is not constant for all colours, being greater for the violet end of the spectrum and less for the red end. It is usual to design for a wavelength near the middle of the spectrum, so that the elliptical image formed in red light will be slightly away from the optical axis, i.e., in general will have its mean axis divergent, whereas at the blue or violet end the mean axis of the elementary cone will be convergent. If, instead of an elementary portion of prism, one considers a complete ring equidistant from the optical axis, then a portion of this ring will produce an independent small elliptical image from a spherical source. At a distance from the lens sufficiently great for these elementary cones to overlap, the elements will fuse into a uniform circular patch surrounded by a region where the intensity falls rapidly to zero.

So far, consideration has been given only to a generalised form of prism section, the sole requirement being that the angle of the prism shall be such that the main ray emerges in a direction parallel to the optical axis. It is clear that there are an infinite number of sections which will fulfil this condition. These include, (i) Prisms with the first face vertical and the curved surface on the outer face; (ii) Prisms with the inside face normal at all points to the direction of the incident light, so that all the refraction takes place at the second surface and both effective faces of the prism are curved; (iii) Prisms where the refraction takes place equally at the inner and outer faces, so reducing aberration to a minimum. These three prism sections are shown in Fig. 2. The design that Fresnel adopted was the first mentioned, namely, the one with the vertical inner face. Mathematical analysis shows that the equi-angular section, that is, the one where refraction takes place equally at both surfaces, does give the minimum aberration and this is the type which has been largely used in Scottish lighthouses. For practical purposes, however, the advantages of manufacturing the Fresnel section outweigh the very slight reduction in efficiency which is involved in its use.

So far the implication is that the radii of the various faces used are constant or, in other words, the sections are circular, but mathematical analysis again indicates that the true curve is highly complex. There are, however, various ways in which a simple circular approximation to the true curve can be achieved. For example, Fresnel designed[4] his prism so that the tangents at the top and bottom corners of the outer surface gave a horizontal direction to the emergent light from a theoretical point source as shown in Fig. 3. Another way of doing this, also shown in Fig. 3, is to approximate to the true curve at the centre of the prism by means of the normal astigmatic formula. The differences in radius of curvature given by these two methods of approach are of the order of 10 per cent., and in general these differences are negligible in relation to the natural divergence consequent on the use of a source of finite size.

All that has been said so far refers to the prime function of a lighthouse

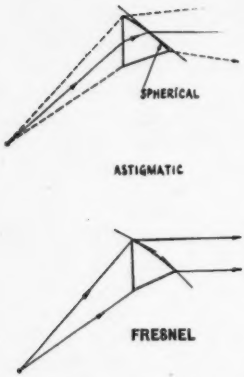


Fig. 3. Alternative designs of refracting prisms.

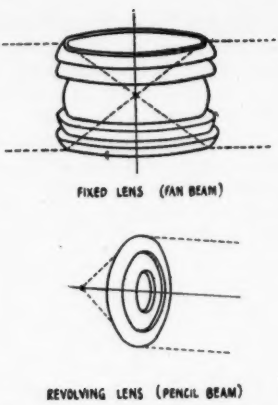


Fig. 5. Fixed and revolving lenses.

lens, which is to achieve the maximum flashed area when the lens is used with a very small source. The second function of a lighthouse lens is to utilise the maximum amount of flux and to project it in the intended direction. For prisms which are relatively near the axis it is appropriate to use simple refracting or dioptric prisms which depend entirely on refraction for the redirection of the light, but at angles above about 45 deg. from the optical axis, which in general is horizontal, the losses by reflection become so great that such prisms rapidly become too inefficient to use. At these wide angles, catadioptric prisms are used in which the light is first refracted, then totally internally reflected, and finally again refracted. By their use it is possible to utilise light emitted at angles up to very nearly 90 deg. from the horizontal. The section of a lighthouse optic shown in Fig. 4 illustrates the use of prisms of these different types.

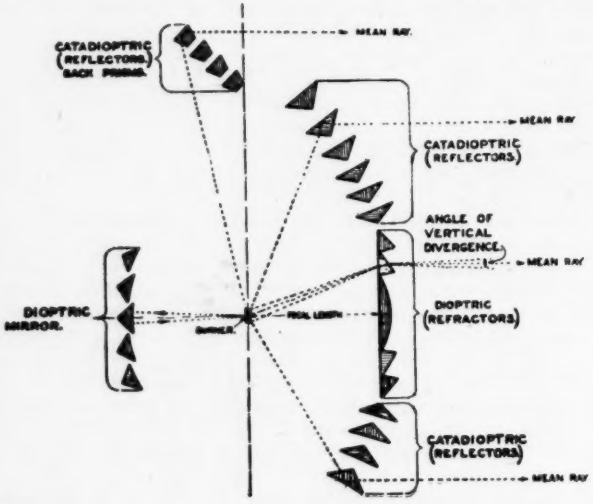


Fig. 4. Section of a lighthouse optic.

(2.4) Pencil- and Fan-Beam Distributions

In all this, consideration has been given only to the vertical section of the prisms, but it is clear that the light emitted by the lens system itself can be dealt with in two ways as shown in Fig. 5. The light can be condensed in a vertical direction only, so as to be emitted in the form of a horizontal sheet or fan, the light being visible in all directions in azimuth. Such an optical system is known technically as a "fixed lens." Alternatively, the light can be condensed both in elevation and in azimuth. In this second system the effective area that may be brought to bear on any one point is very much increased, giving a much-increased intensity in that direction. As the light is emitted in the form of a conical beam, or pencil of light, it can only be seen in the direction in which it points, and to make it visible in time at any fixed point on the horizon it is necessary to revolve the lens system. Such systems are consequently known as "revolving lights."

Fig. 6 shows a large fixed lens of 920 mm. focal length, built prior to 1900, incorporating reflecting and refracting prisms. A revolving lens of the same focal length, which was made for the Fastnet Rock light and consists of two lenses mounted in biform upon a mercury-float pedestal, is shown in Fig. 7.

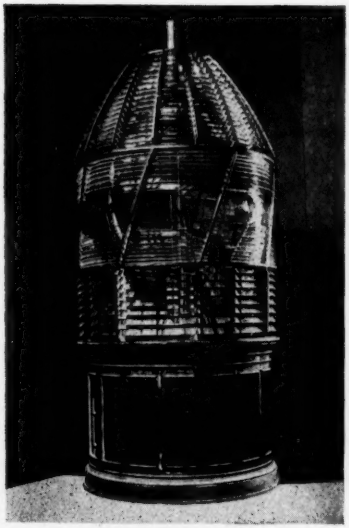


Fig. 6. *(Above).* 1st order fixed lens and pedestal.

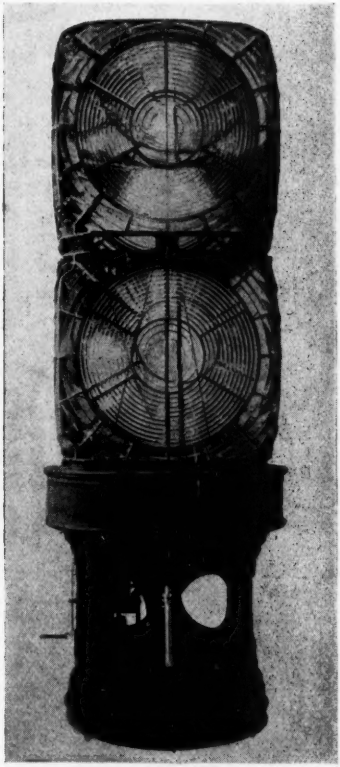


Fig. 7. 1st order biform revolving lens and pedestal.

(3) Calculation of Intensity

From what has been said above it is fairly obvious that the effective intensity of any lens of this type is given by multiplying the brightness of the source by the area of glass which appears flashed in the given direction, multiplied again by some factor appropriate to the form of lens and which makes allowance for the absorption and reflection losses implicit in the lens itself. With a revolving lens, the area involved is the whole area of glass projected in the direction of the optical axis, but with the fixed lens where a sheet of light is emitted through 360 deg. in azimuth, the effective area seen flashed from any point is the height of the lens multiplied by the horizontal width of the light source (Fig. 8). Many papers[5] have been published to enable the various correction factors to be applied, and a British Standards document BS.942[6] gives appropriate values of the reduction factors for any particular design. From a knowledge of the brightness of the light source and the dimensions of the lens, it is possible to make a fairly accurate approximation to the peak intensity viewed along the optical axis for a revolving lens, or in the horizontal plane for a fixed lens. These figures will correspond closely to what would be obtained by a photometric measurement, but for reasons that will appear later, the figures are not appropriate for calculating the effective intensity of a lighthouse lens under operating conditions.

(4) Conspicuity

The main interest in viewing a lighthouse is to see it as far away as possible in order that a ship approaching the danger point marked by the lighthouse shall have as much warning as possible. A great deal of attention has been given in recent years to establishing the level of illumination at the eye of the observer which enables a light to be seen[7]. As would be expected, this figure is not easy to determine, as not only do different observers have very different sensitivities, but the value also varies with the background illumination. It has been known for many years that the range of a flashing light is appreciably less than the range of the same light when it is not flashing. The original Blondel-Rey experiments[8] were carried out with light sources under laboratory conditions where the rise to maximum intensity of the flash was virtually instantaneous and the cut-off was equally short. They found that all their

Fig. 8. Flashed areas of fixed and revolving lenses.

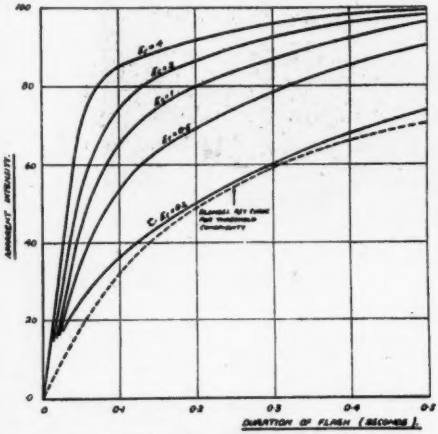


Fig. 9. Fixed light equivalents at different conspicuity levels.

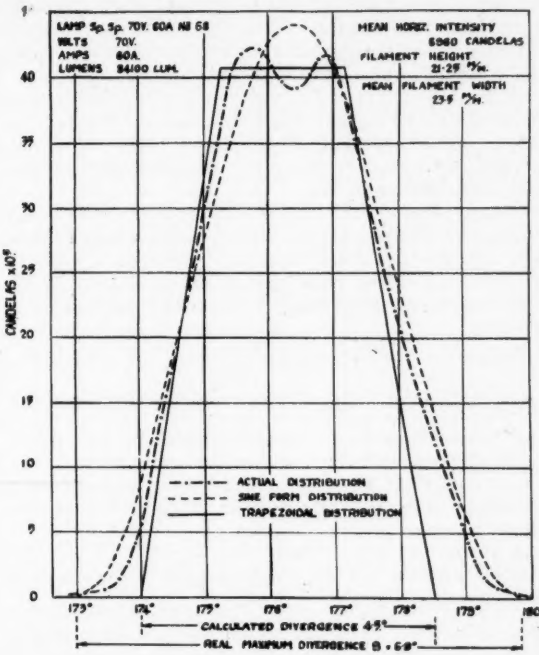


Fig. 10. Van Vloten's approximate trapezoidal form for intensity distribution.

experimental results could be conveniently covered by a formula which may be considered as empirical, although reasons—which are fairly plausible—have been put forward for its adoption. This has the form:

$$I = I_0 \frac{t}{a + t},$$

where I is the fixed light equivalent of a flashing light whose stationary intensity is I_0, t is the duration of flash and 'a' is a constant. Van Vloten[9], who was a distinguished Engineer-in-Chief of the Netherlands Lighthouse Service for many years, applied this type of formula to the results observed on a number of Dutch lighthouses and found that the same form of expression covered his results, although he obtained a different value for the constant 'a'. Toulmin-Smith and Green published in the Journal of this Society in 1933[10] the results of an elaborate series of experiments, which showed that the actual form of the curve relating the fixed light equivalent of a flashing light to the duration of flash varied according to the level of the illumination at which the measurements were made (Fig. 9). In actual lighthouses there is the additional complication that the intensity is not uniform during the flash; this was allowed for in the original publication[7] in a formula of the general type:

$$I = \frac{\int_{t_1}^{t_2} I_0 . dt}{a + t_2 - t_1}$$

Thus it is not possible to provide an appropriate formula for finding the fixed light equivalent of a flashing light until it has been decided at what conspicuity level

one would expect the formula to operate. As a result of both laboratory and full-scale work it has been accepted by the lighthouse authorities that a reasonable value for the illumination at the eye is 0.67 sea-mile candela(7) (= approximately 0.2 micro-lux) and when this value—which is adequate for reasonable conspicuity—is adopted, then from Toulmin-Smith and Green's work it is possible to select a curve which represents the fixed light equivalent as a function of the duration of flash. This leads to a value for 'a' of 0.10 for eclipsed beams, which is the value of 'a' that should be used in the general formula above. The practical application of these formulae is still not completely demonstrated.

As a result of the examination of many distribution curves for lighthouses, Van Vloten(11) found an approximation to the shape of these in the form of a trapezium (Fig. 10). He could have approximated equally well by using a $\sin^2$ or $e^{-\theta^2}$ function, but the result would have been much the same. By the substitution of any of these functions in the generalised Blondel-Rey formula, one can deduce for any desired illumination level the correct form of curve for any flash duration. It is fortunate that this correct curve can then be again approximated by an expression of the form

$$\frac{t}{a+t}$$

provided a different value—and this time a purely arbitrary one—for 'a' be taken; Van Vloten agreed that using the figure of 0.15 for 'a' in this second formula led to a sufficiently close approximation to the true curve to justify its use. This value is used on p.19 in BS.942/49 and its derivation has been amplified in this paper because it has not been clear to a number of users why two different values of the constant should be given in that document.

(5) Range of a Lighthouse Beam

It is now theoretically possible to calculate the stationary axial intensity of a lighthouse as a function of the light source and the lens surrounding it; it is also possible to apply a correction as a function of the duration of flash in order to find the fixed light equivalent of this same lighthouse when it is operating as a flashing beacon; there remains the problem of determining at what distance it will give an illumination

Table 1.

Standard Visibility Code.

Maximum distance of visibility object	Code Figure
Kilometres	
0.05	0
0.2	1
0.5	2
1	3
2	4
4	5
10	6
20	7
50	8
Greater than 50	9

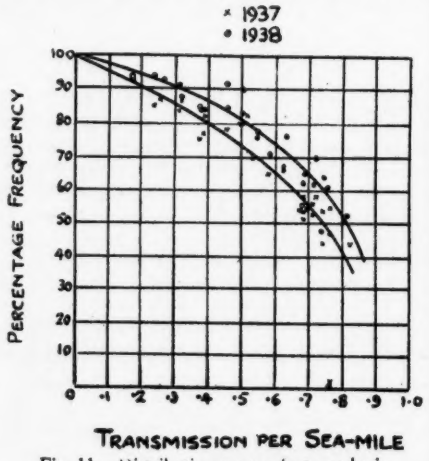


Fig. 11. Distribution curve of atmospheric transmission.

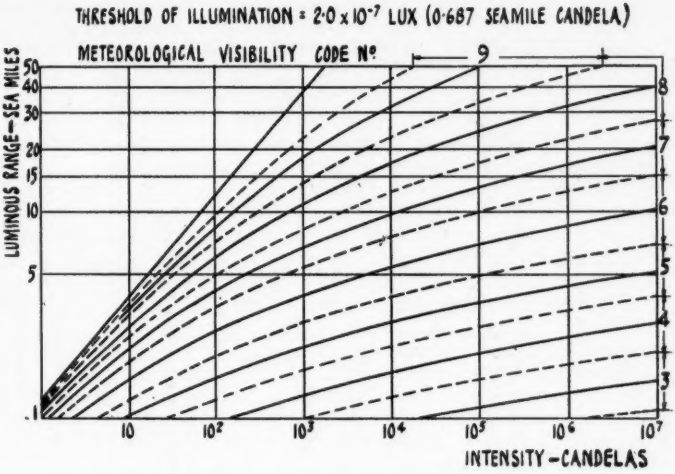
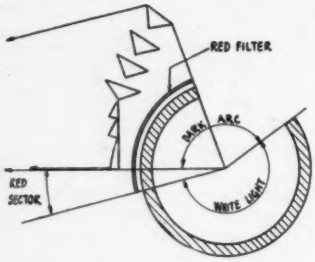


Fig. 12 Relationship between luminous range and intensity for different Meteorological Visibility Code Numbers.

on the eye of an observer which is equivalent to 0.67 sea-mile candela in a theoretically clear atmosphere.

It is usually obvious that the atmosphere in this country, and in fact in any country, is not ideally transparent. It can be shown simply that the light transmitted through a uniform atmosphere is represented by an exponential function in terms of the specific absorption and the distance at which the light is viewed. The formula adopted is that proposed by Allard([12]), in which an arbitrary assumption has to be made concerning the level of conspicuity. Granted that value, the formula allows the range to be calculated for any atmospheric conditions, which are always assumed to be uniform between the light and the observer. It is not possible to determine this directly under the conditions arising at sea, and various indirect approaches have to be made.

Over very many years records have been kept in the lighthouses round the coasts of this and other countries of the number of times the light from neighbouring lighthouses can be seen. These records are usually recorded at three-hourly intervals, so that the number of times a particular lighthouse is visible by its neighbours can be regarded as a percentage of the number of observations made at any particular time: the results are usually published annually. Now it has been shown([13]) that it is possible to deduce approximately the transmission of light through the atmosphere per sea mile from these observations, and to derive a frequency curve similar to that shown in Fig. 11. This still, unfortunately, does not help the sailor in deciding what the atmospheric transmission is at any particular moment when he is looking for a lighthouse, and if he cannot see it he is never sure whether it is because it is not there or because the weather is too thick. Consider now the Standard Visibility Codes([14]) of Table 1 which are applicable to daylight observation. A series of figures is applied to the weather for daylight observation when certain large objects can be seen at various standard distances. These objects, which may be houses, mountains, or something similar, are seen under conditions of daylight illumination by contrast; when the weather becomes hazy the contrast disappears and the object becomes invisible. A formula put forward by Koschmieder([15]) enables the relation between the distance at which these objects can be seen and the attenuation coefficient of the atmosphere to be computed. Combining this equation with Allard's equation



CONDENSING PRISM LIGHT

Fig. 13. *(Above)*. Principle of condensing prism light.

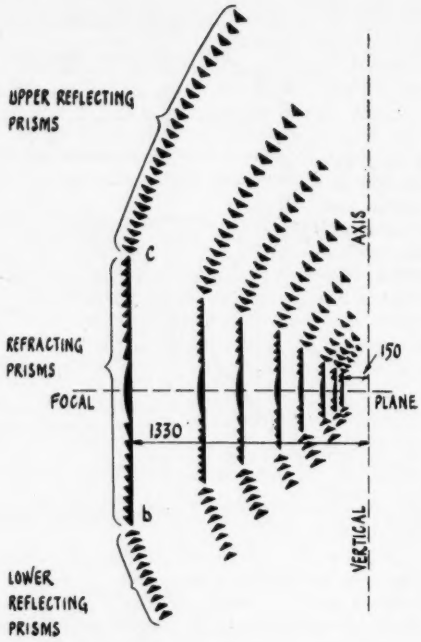


Fig. 14. Various sizes of lighthouse lenses.

enables a formula to be produced from which can be calculated the necessary source intensity in order that this light shall be seen at the distance corresponding with the Standard Visibility Code. The diagram of Fig. 12 relates the luminous range of lights to their intensity for different values of the Standard Visibility Code. It is hoped that it will be possible for the Maritime Services of the world to adopt these, since in the course of years mariners have become accustomed to estimating the Visibility Code fairly accurately; also for forecasts to be made of the probable visibility in any particular place. This information is broadcast, and from this information and a chart, a more reasonable estimate of the probability of seeing a particular lighthouse may be made.

(6) Practical Applications to Lighthouses

The adoption of Fresnel's refracting lens was quickly followed by the invention of many other types of optical agents and combinations of such agents to meet the particular requirements of individual lighthouse stations. For example, totally internally reflecting prisms were devised and assembled in the form of a spherical mirror for collecting light radiated from the light source (burner) in an unwanted direction and reflecting this light back through the source to augment the beams emitted by diametrically opposite lens panels.

Where it was required to show a red or green light over a certain horizontal sector, coloured glass shades were fitted to the lens or the enclosing lantern, but this seriously reduced the beam intensity throughout the coloured sector due to absorption in the colour filters. To compensate for these losses special vertical prisms were mounted outside the lens, arranged to collect light emitted from the lens over an

unwanted (landward) arc, and redirect this light in the direction of the coloured sector (Fig. 13). Such prisms are known as condensing prisms.

Another interesting device was that employed at Souter Point in 1870, where it was required to project a fixed warning beam in the direction of a dangerous rock, in addition to the main flashing light. This was achieved by employing a periscopic principle in which light was collected from the main illuminant by a small fixed catadioptric lens panel placed within the main revolving lens in the landward arc. The beam from the fixed lens panel was then reflected vertically downwards through the lens pedestal and lantern floor via a system of right-angle prisms on to a further set of identical prisms and hence horizontally through a window in the tower wall.

Lenses ranged in size from 150 mm. to 1,330 mm. focal length (Fig. 14). The latter size, termed hyper-radial, were employed with large multiple-wick oil burners, where beam intensities of the order of 1½ mega-candelas were required. Such a lens, weighing approximately six tons and containing 850 separate elements of glass, is shown in Fig. 15.

With the advent of high-luminance electric filament lamps the need for the larger lenses no longer arose wherever electric power could be made available, so that in general the largest lenses supplied to-day are only 500 mm. focal length. It is interesting to note that whereas the hyper-radial lens (1,330-mm. focus) was required to give 1½ mega-candelas with a six-wick oil burner, the same intensity can be obtained with a modern fifth-order (187.5 mm. focal length) lens and a 1-kw. gas-filled electric filament lamp.

The introduction of the small electric filament light source required a higher order of accuracy of grinding and polishing of the individual prisms to ensure homogeneity in the projected beams, and hence better methods of producing the prisms had to be devised. These include the introduction of diamond grinding tools, automatic feeding of carborundum abrasive during grinding operations, and the

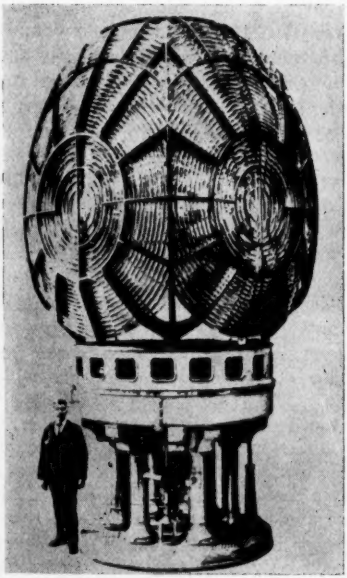


Fig. 15. *(Left).* Large multiple wick oil burner with 1330 mm. focal length lens.

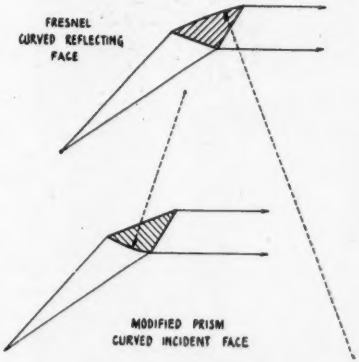


Fig. 16. *(Above).* Alternative designs of reflecting prisms.

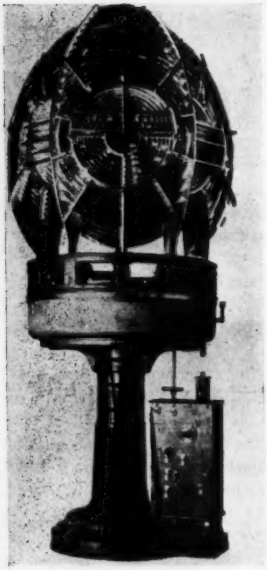


Fig. 17. 2nd order aeromarine light and pedestal.

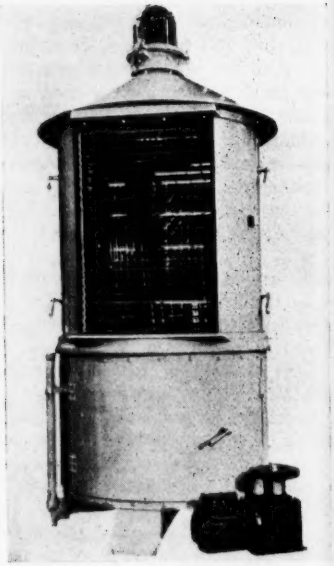


Fig. 18. Single flashing dioptric airway beacon.

Fig. 19. Airway beacon with rotating coding shutters.

substitution of cerium and zirconium oxides for jewellers' rouge as the polishing media.

Furthermore, the reflecting prisms have been redesigned so that the radii of curvature are much shorter than those for the original Fresnel type of prism (Fig. 16), with the result that the curvature can be very accurately generated, and hence the aberrations in individual prisms considerably reduced.

It was perhaps natural that following World War I, when commercial flying was being developed, the services of lighthouse optic designers should be enlisted to devise suitable airway beacons for marking the major air routes. Existing lighthouse lenses were fitted with special diverting prisms which redirected a small percentage—usually 10 to 15—of the light in the main beam in an upward direction at 20-25 deg. above the horizon. Similarly, many new lighthouse lenses were designed for the dual duty of aiding aerial and marine navigation (Fig. 17).

Airway beacons intended for inland routes need only cater for aerial traffic and

hence the lenses for these beacons were specifically designed for this duty although the well-established principles of lighthouse optics were employed.

Fig. 18 shows an airway beacon originally designed in 1933, and now acknowledged to be one of the finest beacons available. This apparatus employs a two-panel inner lens and two corresponding outer condensing lens panels which distribute the emitted light as required from the horizontal to 20 deg. above the horizontal. One of the inner panels carries a green filter so that as the lens is rotated an alternate white and green flashing character is exhibited.

Other forms of dioptric airway and aerodrome beacon have been developed in which the identification character has been obtained either by nigressing the light source or by the use of rotating shutters or screens. The latter type was used extensively during World War II for aerodrome location, the shutters being adjusted to flash a morse letter which could be varied from day to day at will (Fig. 19).

The demand for these beacons was so great that the manufacturing capacity for producing the traditional ground and polished type of lens was totally inadequate, and it was therefore decided to develop a moulded lens which would be interchangeable with the ground and polished one. The complete lens consisted of four cylindrical 90 deg. segments or panels, each panel comprising three mouldings, together with a dome lens of four segmental mouldings. The mouldings were produced to a high order of accuracy and, with the large electric filament source used in service, the lens yielded a beam intensity which was only 10 per cent. less than that from the equivalent ground and polished lens.

The moulding technique acquired during the production of these flashing aerial lights has been applied with great success in post-war years to the manufacture of moulded lenses for marine beacons employing electric sources. Similiarly, smaller ground and polished lenses used on acetylene and electric lighted buoys are now being supplanted to an increasing degree by accurately moulded lenses produced in one piece, either by a pressing or by a centrifugal casting process.

There is no doubt that, as manufacturing techniques continue to improve, moulded lenses for small beacons will become increasingly more attractive from the economic point of view, and may ultimately wholly displace ground and polished lenses for these applications.

Optics for major lighthouses will, however, probably continue to be of the ground and polished catadioptric type, although improvements in the design of lamp filaments or the development of new sources of the gas-discharge type may result in a further general reduction in the size of optical apparatus required to produce beams of the required character and intensity.

It will be noticed that the term " mega-candle " has been used in describing the intensity of lighthouse beams. In 1940 the author had the privilege of describing various floodlights and beacons to their Majesties, the King and Queen, when Her Majesty remarked that the candle was a very small unit in which to measure light of such intensity. The author agreed and decided then and there to invent a " million-candle " unit which has now come into general use.

Acknowledgements

My acknowledgements are due to the many people who have been associated with lighthouse design and manufacture at Chance Brothers, Limited, and especially to Mr. J. G. Holmes, who spent many years with me, and to Mr. Gough, Dr. Willott and their staffs.

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Appendix 1

(1) Symbols

a = Constant for flashing lights in the Blondel-Rey formula.
B = Luminance of source.
d = Night visibility range (miles/kilometres).
E = Point brilliance (mile candelas or lux).
f = Focal length of lens (centimetres).
I_0 = Axial intensity (candelas).
I = Fixed light equivalent of flashing light (candelas).
I_v = Axial intensity of a light just visible at night at distance V (km.).
K = Transmission factor of lens = say, 0.88.
t = Duration of flash (seconds).
T = Atmospheric transmission factor per unit distance.
V = Daylight visibility range (miles/kilometres).
x = Distance (miles/kilometres)
ϵ = Threshold of contrast.
σ = Attenuation coefficient of atmosphere.
ρ = Radius of source (centimetres).
θ_1 = Half maximum angular subtense of lens.

(2) Summary of Formulae

The following formulae assume:

(a) A uniform spherical monochromatic source greater in dimensions than the critical size;
(b) The use of a Fresnel section;
(c) Constant glass absorption of 4 per cent. per inch thickness.

Formulae for Calculation of Axial Intensity

(i) Fixed type lens, refractors only

$$I_0 = 4Bf\rho K\theta_1$$

(ii) Revolving type lens, refractors only

$$I_0 = 2.79\, Bf^2K.log_{10}\cos\theta_1$$

Allard's Formula for Range

$$I_0 = {}^{Ex^2}/_{T^x}$$

Koschmieder's Formula modified for Daylight Visibility Range

$$V = \frac{1}{\sigma} \log_e \frac{1}{\epsilon} = \frac{.4343}{\sigma} \log_{10} \frac{1}{\epsilon}$$

Formula for Calculation of Range of a Light at Night as Function of Daylight Visibility Range (assuming $\epsilon = 0.04$)

$$I_0 = Ed^2e \frac{3.21d}{V}$$

For the particular case of a light which can just be seen at a distance

$$V \text{ a } d = V, \text{ then } I_v = E\,V^2\,e^{3.21} = 5.0V^2$$

when V is in kilometres and $E = 0.20$ micro. lux.

Relationship Between Attenuation Coefficient and Atmospheric Transmission Factor

$$\log_e T = -\sigma$$

Discussion

CAPTAIN G. CURTEIS: I would like to make a few very brief observations. In these days when monopolies are regarded with suspicion it is, I think, a matter for congratulation that in holding a nationally monopolistic position for something over a century, the firm with which the author is associated has kept abreast of—and in many ways has led—in technical developments. Many lighthouses throughout the world have been built in the factory at Smethwick, and the firm is known throughout the world in lighthouse and maritime circles. I think it is a continuing marvel to the uninitiated how they take these rough pieces of glass, shape, grind and polish them, fit them into frames, and with a comparatively small source of light produce these enormously powerful beams.

I think it is always of interest to see and hear an expert at work, and I do not suppose there are many people who know more about the technical and practical side of lighthouse optical work than Dr. Hampton. It was, therefore, quite certain that his paper would be of very great interest, and I think the way in which he put across many of the mathematical ideas which are involved in the design of lighthouse lenses was particularly skilful.

The figures shown of the various lighthouses illustrate to some extent how essential are complete reliability and first-class workmanship in this form of optical work. I would not say that price is not of importance, but where the safety of seaborne shipping depends on complete reliability of equipment, price must be a secondary consideration.

The suggestion that ranges of lighthouses at night should be expressed in terms of the day visibility code was first put forward by Dr. Hampton at the Lighthouse Conference in Paris last year; all engineers present received it favourably, and it is to be hoped that we shall shortly obtain international agreement.

DR. S. ENGLISH: It is with very great pleasure that I join in this discussion—a pleasure which springs from my long and close association with Dr. Hampton which has extended not only over a long period of time but also over a wide range of interests.

I think it must be clear to all of us that when we come to a specialist subject like the design and manufacture of lighthouse optics, it is essential to have a combination of three, or perhaps four, sciences, and if you can get two or more sciences combined in one man, so much the better—for he will not argue with himself. Dr. Hampton can handle not only glass technology, but also the illuminating engineering side, and he has

more than a nodding acquaintance with the mechanical engineering side. Each of these three is particularly important in the construction of these complicated optics.

There is more to be said about the glass technology aspects than Dr. Hampton has given in his paper. Let us look at the raw materials with which the glass engineer and the optic designer and manufacturer have to start—rough lumps of glass—but this glass is very different from the ordinary glass with which we as illuminating engineers are familiar. Glass to be used for optics must be of infinitely higher quality, it must have optical and physical properties which are accurately known and constant to a very high degree, and it must have a permanence comparable to that of a noble metal, for as Dr. Hampton mentioned, the conditions which these optics have to withstand, i.e., sea atmospheres, are particularly corrosive and would quickly destroy the polished surfaces of non-durable glasses.

Then you come to the working of that raw material into prism bands, the angles of which are calculated very precisely and which have to be reproduced on those complicated lenses to a fraction of a degree. The precision of the grinding and polishing of the prism surfaces is so high that it cannot be measured by ordinary mechanical methods but must be checked by optical means.

Turning to the mechanical side of the job, it is obviously no use designing to a high degree of accuracy and making glass to the same degree of accuracy and then assembling carelessly. The assembly of these independent pieces of glass to make a complex optic is a mechanical engineering job which is nothing short of startling. These rings of glass must be assembled and secured permanently in the metal frame of the optic to a degree of precision which is measured in hundredths of an inch. It seems amazing to have, say, 850 pieces of glass of such uniformity, formed to such accuracy and then assembled as a lens with a precision that ensures each single element contributing its proper quota to the beam emitted by the whole system.

It is interesting to realise that the introduction of high power, high brightness electric lamps has permitted a reduction in size of these optics, so much so that for certain apparatus it is possible now to mould the lens at the furnace instead of having to take rough glass, grind, polish and assemble. In this connection there is one process I have not seen in operation, and that is centrifugal casting by spinning instead of pressing by mechanical means. When in Germany in 1945, Dr. Hampton and myself came across this process, but it was not possible then to see it in operation, though we saw and admired glassware said to have been produced by this method. I would be interested to know if Dr. Hampton has had any success with this process.

Finally, I would like to add a point along the same line as that mentioned by the President in inviting discussion on this paper.

It is rather more than 100 years since lighthouse design and manufacture was taken up in this country and during the intervening century British designed and built lighthouses have been put into operation, not only all round our own shores but in many parts of the world, and yet very few people know anything about it. A short while ago I saw an article which was written by an American for American illuminating engineers, in which he told his fellow countrymen that other countries had contributed something towards the sum total of knowledge and progress in different branches of illuminating engineering, which did not seem to be appreciated by quite a lot of people over there. Among the examples quoted were lighthouse optics, but these were attributed to another country and England was not even mentioned, in spite of the fact that we have done in this country as much work on this subject as anybody else. As a matter of fact, Americans coming over here by sea, leave their own shores guided by the light from a British designed and built lighthouse, and their first contact with land on this side of the ocean is again a lighthouse "made in England." It is high time that we made such facts known. This paper might go some way towards telling others that we have men in this country who are

in the front rank of development scientists and engineers, and that the products deriving from their labours are outstanding in many respects.

DR. J. M. ALDINGTON: It has been sometimes said that developments in the field of electric filament lamps have been static for a number of years. With others, I have sought to show from time to time before this Society that this is not true, and nowhere is it less true than in connection with tungsten lamp sources for lighthouse optics. I was very interested in the slide by which Dr. Hampton showed the measure of the reduction in the size of a lighthouse optic which was brought about by the introduction of high brightness electric filament lamps for lighthouse work. Since that time there has been evolutionary progress but we have now, I think, reached the stage in which the designers of lighthouse equipment must so formulate their requirements that the designers of tungsten filament lamps may still further improve their sources. Over the years we have developed means of improving our control of the shape, size and efficiency of the filaments of projection lamps. We now need guidance about the direction in which development should proceed. This phase can perhaps be summed up as that of development in the direction of increasing fitness for purpose.

When we turn to the suggestion at the end of Dr. Hampton's paper regarding the future possibility of utilising existing discharge lamps for lighthouse optics, I must confess to a little disappointment that so far it has not been found possible to make really effective use of the electric discharge lamp in this way. Many of the properties of existing sources make them appear suitable or even desirable. There are, however, corresponding disadvantages but we do appear to be entering a phrase when some of the newer gas discharge sources might perhaps be considered very seriously with a view to bringing about further increases in the effectiveness of lighthouse optic and lamp combinations. I have in mind Gas Arc lamps of the type using xenon. Such sources are being used experimentally with considerable success in cognate apparatus to that described by Dr. Hampton. Similarly the possibility of using the very high brightness flashing sources for lighthouse work might be reconsidered, and it would appear from the Blondel-Rey relationship that when dealing with flash periods of say 1,500 microseconds it would be possible to produce a source brightness of several thousand times that of the filament lamp. In view of the complex physiological effects involved, a lot of experimental work would be needed to determine whether an effective gaining range could be obtained, but I should like to hear Dr. Hampton's views.

MR. J. LAWSON RUSSELL: I would like to add my tribute to those already paid to Dr. Hampton; a paper by him is a major event in the lives of those of us interested in lighthouses or aviation beacons.

Dr. Hampton has referred to the Koschmieder formula which in its simplest form states that the visibility is the distance through which the transmission is equal to the contrast threshold, usually taken as 0.02. The transmission for any distance, d, is then 0.02 d/V where V is the visibility. The contrast threshold value used in calculating Fig. 12 is apparently 0.02. This value has been used for many years in aviation lighting calculations and it now has the blessing of our Meteorological Office, but some writers, notably Douglas of the American Bureau of Standards, have suggested a higher value. Middleton in Canada has tackled the problem in a highly realistic way by checking the transmission at the same time as meteorological officers were estimating visibility. He found that in 649 observations by 11 observers the most frequent value of transmission was 0.02 but the mean was 0.041 and the median 0.034. I understand that the C.I.E. *ad hoc* committee on aerodrome lighting is proposing to adopt a value of 0.04. Dr. Hampton has said that he hopes the Maritime

Services of the world will adopt the relationship shown in Fig. 12. I think it would be a great pity if two different international agreements were reached. My own opinion is in favour of the 0.02 value, if only because it is less likely to give optimistic estimates of performance.

I am very glad that Dr. Hampton has explained the use of two values of the Blondel-Rey constant in BSS 942. His explanation will also cover the choice, which I understand has been made on his recommendation, in the revised edition of the B.S. Guide to Aerodrome Lighting now about to be published. In this same Guide I believe you will find a strange formula for the light distribution of an aerodrome beacon. The main beam from such a beacon is required to cover angles between 1 deg. and 3 deg. above the horizontal because aircraft approaching to land would usually be within these angles, but on occasions, particularly when the visibility is not very good, aircraft will be above the main beam. It was decided to take about half the light flux from the beam, thereby reducing its range by perhaps 10 per cent., and distribute it between the angles of 3 deg. and 20 deg. above the horizontal. This has been done by requiring the intensity to fall inversely as the square of the angle of elevation. The effect of this is that the range of the beacon falls gradually to a value at 20 deg. elevation of rather more than half its maximum. The beacon which Dr. Hampton has mentioned was I think designed to the requirements of the pre-war BSS 563; nevertheless it meets the new requirements with something in hand and its very satisfactory performance is taken as some justification for the new formula.

I am disappointed that Dr. Hampton has given us no information on the choice of flash duration. As Dr. Aldington has pointed out, it is now possible to use light sources with flash durations of a few microseconds, and, according to the Blondel-Rey formula, the shorter the flash the greater the range for a given energy. I believe that very short flashes should not be used because, unless they are repeated rapidly, it is not possible to form an impression of the position of the beacon.

I have not made a proper study of this problem, but a paper by Blondel (Comptes Rendus des Sciences, 1937) has a bearing on it. He reported that the flash duration of some French lighthouses had been reduced to as little as 1/10 second and that some mariners had complained about it. M. Blondel goes on to show that for a light to be seen foveally at any given range it would be necessary to increase the light flux very considerably above that required to give the same range parafoveally: firstly, because the parafovea may be up to 60 times as sensitive as the fovea, and, secondly, because the flash duration would have to be increased to give time for the eye to move the image on to the fovea and then to see it foveally. He quotes a previous paper by Broca and Turchini (Comptes Rendus, 1924) showing that the time of movement may be 1/20 to 1/12 second.

I think a better approach to this problem is to examine the effect of flash duration on range. Assuming that it takes 1/10 second for an observer to see a beacon and move his eye on to it, then the fixed light equivalent of that part of the flash seen foveally will be :—

$$I = \frac{S}{t} \frac{(t - 0.1)}{(a + t - 0.1)}$$ where S is the candle second value of the flash, i.e., the time intensity integral.

If S is constant and $a = 0.1$ this expression has a maximum when $t = 0.2$. This maximum does not vary rapidly with the Blondel-Rey constant; a value of $a = 0.3$ would give $t = 0.27$.

Applying this argument to a beacon giving a flash of 100,000 candle seconds, if the flash duration is made 0.2 second the foveal range in a meteorological visibility of 20 miles would be about 32 miles and the corresponding parafoveal range 49 miles, taking a sensitivity ratio of 60. If the flash were made extremely short the parafoveal

range would be increased by less than 10 per cent. and the worse the visibility the smaller the difference.

In my opinion it is well worth while to sacrifice something less than 10 per cent. of the ultimate range in order to give an observer an opportunity of forming a good impression of the position of a light. I would like to know whether Dr. Hampton has investigated this problem.

MR. S. S. BEGGS: Although this paper provides an excellent introduction to the very specialised subject with which it deals, I was a little disappointed for I had hoped that Dr. Hampton would go on to discuss more broadly some of the conclusions affecting the rather less specialised field of the illuminating engineer, such as those relating to aviation lights. Thus, I hoped he would give us guidance not only in the design of the lens as such, but on different lens assemblies and types of beam, and whether for example a beacon giving long flashes at long intervals would be more conspicuous than one giving a series of short flashes in quick succession.

Another point on which I should like some guidance is the effect of the size and shape of the source. I imagine that lighthouse lenses were designed originally for mantles and similar sources, and were designed for the particular size of the source. I would be interested to know how far the designs have been modified by the different shapes which are possible with the filament lamp, and what shape and construction of filament is the best.

As I read the paper, I understand Dr. Hampton to state that the size of the lighthouse lens is calculated to produce a beam intensity which would give a range (at night) equivalent to the daylight visibility range—presumably for some chosen weather condition. Is this a correct reading of the statement, for the reason for such a procedure is not clear?

I was very interested in the comparison of the moulded lens with the ground and polished lens. My own experience is that there is considerably more than 10 per cent. difference between an optically worked lens and a moulded one unless the moulded lens is polished. Are these lenses merely moulded or are they polished after moulding? In a fully flashed optical system such as a lighthouse lens the intensity depends on the brightness, and the surface finish is particularly important.

DR. J. W. T. WALSH: I should like to enter a strong protest against the introduction of this horrible new unit of illumination, the sea-mile-candela. We are, with some difficulty, getting rid of the foot-candle, at least on this side of the Atlantic, and replacing it with the lumen per square foot. The natural unit to replace the one used by Dr. Hampton would thus be the lumen per square sea-mile, but that does not seem a happy conception and I strongly urge that we should adopt a sub-multiple of the principal unit and use the micro-lumen per square foot where appropriate. It is true that, owing to the fact that our system of length units is not a decimal one, the illumination produced by one candela at a distance of one sea-mile is not a decimal sub-multiple of the lumen per square foot but that should present no difficulty except initially and until it is realised that the sea-mile-candela is, in fact, $1/36 \times 10-6$ lumen per square foot or 0.028 μ 1m./ft.^{2}.

THE PRESIDENT: The work done by Dr. Hampton in the preparation and revision of British Standard 942—"Formulae for Calculating Intensities of Lighthouse Beams"—is rapidly gaining acceptance by the authorities concerned with signalling all over the world. This British Standard gives simple and reliable methods of calculating the peak beam intensity, the beam spread, the duration and effective intensity of a flashing light and the atmospheric absorption. In the 1949 revision, the data for the correction factors has been modified for Fresnel lenses, compared with the earlier data based on Dr.

Hampton's fundamental calculations (Reference 5 in the paper), and new data are given for equi-angular lenses; could Dr. Hampton include in his reply to the discussion a summary of the theoretical considerations underlying the data now given?

MR. L. H. HUBBLE (Written Contribution): Most amateur yachtsmen are happy to donate generously to the R.N.L.I., and it is much in the same spirit that I should have liked personally to have thanked Dr. Hampton, not only for his interesting paper but for materialising as the fellow behind that welcome light at sea.

We have all from time to time attempted to prove our D.R. position from a single bearing taken with a badly lit standard compass on a beastly night, only to find on going below to plot our new position that we are indubitably in the middle of a ploughed field! Having hitherto been at the receiving end of the Nab, St. Catherines, the Needles, Anvil, Shambles and Portland—to say nothing of the Start, Eddystone, Lizard, Wolf and Longships—it was most interesting to learn something of the theory and design of these optics, and I can only hope that Dr. Hampton will address us again with a development of his theme.

This lecture is basic, now please may we have the practice and perhaps a little romance? Thank you, Dr. Hampton, and thank you, Captain Curteis, for all that Trinity House do gratuitously for the likes of us!

DR. W. M. HAMPTON (replying to the discussion): Obviously Dr. English is disappointed with me for not showing centrifugal casting—a process which we saw in Germany in 1945. We have made castings by this process—if I am allowed to risk a prophecy I think it is the method of the future—but it is still in the future.

Regarding Dr. Aldington's remarks, I would say that one of the things we are investigating at present is the effect of the shape of the filament and the layout of the particular lamp, on the lighthouse beam, and a lot of interesting things are coming out, but there is a great deal still to be done.

I am not going to get involved in a Blondel-Rey discussion because there are many complications when you get down to micro-second flashes, and I do not know enough about it to make any adequate comment.

I thought somebody would say something about the two values in B.S. 942—I have had to explain this so often to so many people that it was obviously obscure in the first place. I hope it will be cleared up now.

I have had some slight association in the past with aviation lighting, and I can assure maritime people that their problem is very much simpler because ships only operate in two dimensions, but aircraft operate in three, which certainly complicates matters

On foveal, and para-foveal vision and flash duration, I have no information; Mr. Russell is obviously making a study of this, and I hope he will be able to make more information known.

On the size and shape of the source, I have already indicated that we are looking into possible improvements there; very little is known, as a matter of fact, and investigations are difficult, involving full-scale apparatus.

I am asked: "What is the basis of the design of a lighthouse?" In the first place, we have to know whether electric power is available, or whether oil has to be brought to the site, or whether a pipe can be run across from the mainland. Then the engineer decides that the light should be seen so far, so many times in the year—which gives the range. The rest is more or less fixed. The character must, of course, be decided upon so that there will be no confusion with any other light in the vicinity.

I am sorry my figures for the performances of moulded lenses were doubted; the moulded lenses were not polished but very carefully made, and whereas ordinary ship's

light lenses are polished, these were not because any polishing spoils the accuracy of the curves, although the appearance is improved.

The President asked that I should include in my reply to the discussion a summary of the theoretical considerations underlying the new data for equi-angular prisms in the latest version of British Standard 942. I regret that it does not seem practicable to comply with this suggestion, as any explanation of these figures would involve a mathematical discourse which seems inappropriate to the present paper. I hope it will be possible to publish a full version of this in the near future.

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

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Holland House Electrical Co., Ltd. ..... *Representative*: F. Dunnet
221, St. Vincent Street, Glasgow, C.2.

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Newman, W. P. ....." Mametz," 10, Bitterne Crescent, Bitterne, SOUTHAMPTON.
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Nicholls, W. A. .....c.o. The Electricity Trust of South Australia, Box 412C, G.P.O. Adelaide, SOUTH AUSTRALIA.

STUDENTS:—

Chisholm, P. F. .....c.o. Phillips Electrical Industries of New Zealand, Ltd., G.P.O. Box 2097, WELLINGTON, N.Z.
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Ogden, K. W. .....41, Percival Road, Rugby, WARWICKSHIRE.
Overton, G. E. .....682, Kings Road, Kingstanding, BIRMINGHAM, 22C.

Summer Meeting

Eastbourne, May 20-23, 1952

Details of the forthcoming summer meeting at Eastbourne have been circulated to members of the Society, and it is apparent from the returns already received that there will be a good attendance.

The provisional programme is as follows:—

Tuesday, May 20

8.45 p.m. *Civic reception.*

Wednesday, May 21

10.0 a.m. OFFICIAL OPENING.
10.15 a.m. PAPER: The Eye, Brightness and Illuminating Engineering, by Dr. W. S. Stiles.
10.30 a.m. *Ladies' Reception.*
2.30 p.m. PAPER: Two Frontiers of the Lighting Art, by H. L. Logan. (*Holophane Co. of New York.*)
4.30 p.m. *Visit to the Glyndebourne Opera House.*

Thursday, May 22

10.0 a.m. PAPER: Problems of Underwater Illumination, by W. D. Chesterman and J. B. Collins.
2.30 p.m. ANNUAL GENERAL MEETING.
Address: Interior Lighting Developments in the Netherlands, by L. C. Kalff (*N.V. Philips, Eindhoven*).
7.0 p.m. *President's Reception and Dinner-Dance.*

Friday, May 23

10.0 a.m. PAPER: Lighting in the Design of Schools, by A. Pott.
2.30 p.m. PAPER: The Design of Interior Lighting Equipment, by L. H. Hubble.
2.30 p.m. *Ladies' visit to Battle Abbey.*

Full details and registration forms may be obtained from the Secretary.

Student Membership

The Council of the Society has decided that the subscriptions of student members who have already paid one or more annual subscriptions and who are called up for National Service may be waived during the period of such service subject to the student member notifying the Society of his call-up.

ELECTION OF OFFICERS AND COUNCIL

SESSION 1952—1953 OFFICIAL NOTICE

IN accordance with the procedure specified in the Articles of the Society, a list of existing Officers and Members of Council, of vacancies occurring and of duly qualified persons nominated by the Council for vacancies about to occur in the offices of President, Vice-Presidents, Hon. Treasurer, Hon. Secretary, Hon. Editor of Transactions, and Ordinary Members of Council, is presented below for the information of the Members of the Society.

In the event of any Members desiring to put forward other names, the Council will be pleased to receive such nominations, which should be made in accordance with the following rule (Article 48):—

> "After the issue of the Council's list, and not later than the 15*th day of April* next following, any ten Members (but no more than ten) may nominate any other duly qualified person to fill any such vacancy by delivering such nomination in writing to the Hon. Secretary, together with the written consent of such person to accept office if elected, but each such nominator shall be debarred from nominating any other person for the same office at such election."

Nominated by the Council to fill Vacancies :—

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Dr. W. J. WELLWOOD FERGUSON, M.B., CH.B.,

***Vice-Presidents* :—**

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Mr. E. C. LENNOX (*Fellow*).
Mr. A. H. OWEN (*Fellow*).
Mr. J. F. STANLEY, B.SC.
Mr. W. J. P. WATSON (*Fellow*)

***Members of Council* :—**

Mr. A. D. S. ATKINSON
(*Engineer, Lighting Service Bureau*).
Mr. F. M. HALE
(*Engineer, Ministry of Transport*).
Dr. R. G. HOPKINSON
(*Engineer, Building Research Station*).
Mr. J. S. MCCULLOCH
(*Consulting Engineer, R. W. Gregory and Partners*).
Mr. W. T. F. SOUTER
(*Sales Director, Holophane, Ltd.*).
Mr. W. R. STEVENS
(*Physicist, Research Laboratories, General Electric Co., Ltd.*).
Dr. J. W. STRANGE
(*Physicist, Research Laboratories, Thorn Electrical Industries, Ltd.*).
Mr. D. L. TABRAHAM
(*Manager, Lighting Department, General Electric Co., Ltd.*).

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(ex-officio)

To be appointed before October 1, 1952.

***Hon. Treasurer* :—**
Mr. W. J. JONES

***Hon. Secretary* :—**
Mr. H. C. WESTON

***Hon. Editor of Transactions* :—**
Dr. W. E. HARPER

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SESSION 1951-1952

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Mr. W. J. Jones (1951)

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Mr. H. C. Weston (1951)

Hon. Editor of Transactions :—
Dr. W. E. Harper (1951)

The names in italics are those of Officers or Members retiring in 1952. The date in parentheses after each name indicates the date of election to Office or Membership of the Council.

* Filling casual vacancy (1951-53).
† Retiring after filling casual vacancies. Eligible for re-election.
‡ Filling casual vacancy (1952-53).

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